Animal (2018), **12:10**, pp 2130–2137 © The Animal Consortium 2018
doi:10.1017/S175173111700341X

Effect of rubber mats and perforation in the lying area on claw and limb lesions of fattening pigs

A. Falke[1], K. Friedli[1], L. Gygax[1,4], B. Wechsler[1], X. Sidler[2] and R. Weber[3†]

[1]Federal Food Safety and Veterinary Office FSVO, Centre for Proper Housing of Ruminants and Pigs, Tänikon 1, 8356 Ettenhausen, Switzerland; [2]Department of Farm Animals, Division of Swine Medicine, Vetsuisse Faculty, University of Zurich, Winterthurerstrasse 260, 8057 Zurich, Switzerland; [3]Agroscope, Centre for Proper Housing of Ruminants and Pigs, Tänikon 1, 8356 Ettenhausen, Switzerland; [4]Animal Husbandry, Albrecht Daniel Thaer-Institute of Agricultural and Horticultural Sciences, Faculty of Life Sciences, Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany

(Received 10 May 2017; Accepted 13 November 2017; First published online 15 January 2018)

Claw and leg lesions are frequently observed in finishing pigs and are likely to compromise their welfare. Providing softer than the usual concrete flooring may reduce both the frequency and severity of these lesions. Therefore, this study evaluated the influence of rubber mats and floor perforation in the lying area on claw and leg health of finishing pigs. A total of 240 Swiss Large White finishing pigs from on average 24.9 kg until 102.3 kg were used in four batches, with six groups of 10 animals per batch. The six experimental pens initially measured 1.85 × 3.55 m and were enlarged after 6 weeks to 1.85 × 5.25 m. In all pens, one third of the floor space was built as a defecating area consisting of a concrete floor with 15% perforation. The remaining two thirds of the pen were designed as a lying area whose floor quality differed between the pens. It either consisted of concrete elements or was covered with rubber mats, and perforation of both floor types was either 0%, 5% or 10%. All individuals were scored for claw and leg lesions at the beginning, in the middle and at the end of the 12-week fattening period. Lesions were summarised in scores based on the results of a principal component analysis. The influence on lesion scores of floor material, amount of perforation in the lying area, assessment time, and sex was examined using mixed-models. The total claw lesion score and the total limb lesion score as well as the claw angle increased from the beginning to the end of the fattening period. The values for both scores were slightly lower for animals kept on rubber mats compared with animals kept on concrete floor. There was no effect of the percentage of perforation on the examined outcome variables. In conclusion, our results indicate that rubber mats in the lying area bring about improvements in some aspects of claw and leg health in fattening pigs, whereas there is no effect of floor perforation.

Keywords: claw lesions, leg lesions, rubber mat, finishing pig, lying area

Implications

Finishing pigs kept in pens with concrete floors are often affected by claw and limb lesions. While straw bedding is not suitable for many production systems, specifically designed rubber mats could constitute a functionally adequate alternative. In this study, we compared rubber mats with concrete and varied the amount of floor perforation in the lying area. Our results show that rubber mats have beneficial effects on some aspects of claw and leg health, whereas the effects of floor perforation are minor.

Introduction

In modern pig production systems the majority of finishing pigs are kept on concrete floors with slats. These floors differ markedly from the woodland habitat of the wild boar, which is the principal ancestor of modern European domestic pigs (Larson *et al*., 2005) and have raised welfare concerns in respect to claw health. In particular, finishing pigs are often affected by claw and limb lesions. For example, Mouttotou *et al*. (1999a) investigated 4038 finishing pigs reared on 17 farms in the United Kingdom at slaughter and found an overall prevalence of foot lesions of 93.8%. In Switzerland, Lippuner (2012) examined 692 finishing pigs of different breeds kept in pens with partly slatted concrete floors and found wall bleeding in 66.8%, longitudinal wall cracks in 39.7% and heel erosions in 29.3% of the claws. Furthermore, lesions of the integument of the limbs, in particular wounds and pathologic remodelling processes such as hyperkeratosis and the formation of auxiliary bursae, are often seen in finishing pigs. For example, Quinn (2014) reported a prevalence of 25.4% for wounds, 99.5% for hyperkeratosis and 29.6% for bursae in 1289 finishing pigs housed in pens with fully or partly slatted floors without bedding on 68 farms in Ireland.

† E-mail: roland.weber@agroscope.admin.ch

Several studies have shown that the prevalence of limb lesions differs between housing systems with fully and partly slatted flooring. Gillman *et al.* (2008) observed a lower prevalence of bursae in pigs housed in pens with a partly slatted concrete floor (46.6%) compared with those reared in pens with a fully slatted concrete floor (61.5%). In line with this, the risk of bursae and wounds was higher in fully slatted pens than in pens with a partly slatted floor in a cross-sectional study by Quinn (2014). With regard to claw lesions, studies comparing pens with fully and partly slatted flooring have been contradictory. Some studies found no effect on claw lesions of perforated compared with solid concrete floors (Newton *et al.*, 1980; Rähse, 2006), whereas others did (Geyer, 1979; Mouttotou *et al.*, 1999a; Gillman *et al.*, 2009). In summary, these data indicate that the pigs' claws and limbs are overly strained by slatted concrete floors.

Several factors may be responsible for the prevalence of claw and limb lesions observed in finishing pigs kept on slatted concrete floors. Newton *et al.* (1980) addressed the degree of traction, roughness and abrasiveness of the flooring as main sources of claw damage, whereas Savary *et al.* (2009) attributed the occurrence of hyperkeratosis to the flooring material alone. In several studies, the prevalence or severity of claw and limb lesions in finishing pigs was found to be reduced on softer floorings, that is on straw-bedded floors (Jorgensen, 2003; Scott *et al.*, 2006). Rähse (2006) reported an overall prevalence of 28.4% for moderate to severe claw lesions (deformities, pressure sores and contusions, indentations, heel lesions, cracks) in finishing pigs kept in pens with deep-straw bedding *v.* 58.8% in pens without bedding and 65.9% in pens with sparse straw bedding. In a cross-sectional study by Mouttotou *et al.* (1999b), bedding in the lying area and in the whole pen was associated respectively with a 0.29- and 0.11-fold decreased risk of bursae.

Despite its predominantly positive effects on claw and limb health, straw is not used as a bedding material in modern pig production, as it is incompatible with the widely used liquid manure systems. To improve floor quality without use of straw, rubber mats were developed recently for pig housing systems and could constitute an adequate alternative in regard to claw and limb health. They provide a softer, more flexible surface and offer more traction (Von Wachenfeldt *et al.*, 2010) compared with concrete flooring. Several studies have investigated the effects of rubber mats on claw and limb health in gilts and pregnant sows. Calderon Diaz *et al.* (2013) observed less severe swellings, but also a greater risk of higher scores for hyperkeratosis on the legs and claw lesions, in gilts kept in pens with a slatted concrete floor covered with rubber slat mats compared with pens without such a covering. In a study by Bos *et al.* (2016), sows kept in pens covered with rubber mats in the lying area and a slatted area during gestation scored better for several claw lesions (heel overgrowth and erosion, heel-sole crack, white line), but also worse for the lesion type vertical crack in the wall horn, compared with sows housed in pens with partially slatted concrete floor. It is therefore of interest to know whether rubber flooring also has effects on claw and limb health in finishing pigs.

In the present study, we compared the development of claw lesions and lesions of the integument of the limbs as well as claw measures of finishing pigs housed in pens with either rubber mats or concrete flooring in the lying area. At the same time, the effects of different amounts of perforation (unperforated, 5%, 10%) were investigated for both types of floors. We expected claw and limb lesions to rise in prevalence over the fattening period. With regard to floor quality, pigs kept in pens with rubber mats in the lying area were expected to show fewer and less severe claw and limb lesions compared with pigs reared in pens with no mats. We also expected claw angles to be smaller and claw width to be wider in pigs kept in pens with mats. Finally, we hypothesised that pigs kept on floors with perforation of 5% or 10% in the lying area would have more and more severe claw and limb lesions compared with animals housed in pens with an unperforated lying area.

Material and methods

Experimental design and housing conditions

The study was conducted on the experimental farm of Agroscope in Tänikon, Switzerland, from September 2013 to November 2014. A total of 240 sex balanced Swiss Large White fattening pigs were included in the study. After weaning, all animals were kept in pens where the solid floor was covered completely with deep-straw litter and thus had no access to concrete floor before being introduced into the experimental pens. The experiment consisted of four batches in six groups of 10 animals each. The experimental period was 12 weeks per batch, covering the growth interval from 25 to 100 kg BW.

The groups were kept in six rectangular pens which initially measured 1.85×3.55 m, providing a total space allowance of 0.6 m^2 per pig. After 6 weeks, the pens were extended to 1.85×5.25 m to provide 0.9 m^2 per pig. This was done by removing a partition in the rear and relocating the front wall of the pen. By doing so, the pen measurements met the minimum standards, defined in the Swiss animal welfare legislation, over the whole experimental phase. Each pen contained a lying area (initially 0.4 m^2 per pig, extended to 0.6 m^2 per pig after 6 weeks) and a defecating area (initially 0.2 m^2 per pig, extended to 0.3 m^2 per pig after 6 weeks).

The quality of the lying area differed between the six pens in respect to material and the percentage of floor perforation. In three pens, it was covered with rubber mats for pigs with a shore value of 60 ('Porca Relax', Kraiburg Elastik, Tittmoning, Germany). One pen each was equipped with an unperforated mat, a mat with 5% perforation and a mat with 10% perforation, respectively. The perforation was in the form of longitudinal gaps with a width of 15 mm, a gap length of 180 mm and a slat width of 153 mm (5% perforation) or a gap length of 190 mm and slat width of 110 mm (10% perforation). The rubber mats were attached to the underlying concrete slats as recommended by the manufacturer, using specifically designed nail plugs. In the remaining three pens the lying area consisted of concrete elements which were either solid or had 5% or 10% perforation and gap widths of 18 mm with the same gap length and slat width as the rubber mats. To help the drainage of fluids, the floor of the lying area in the two unperforated variants was sloped (3%). The six different variants of lying areas were distributed randomly in one room with no positional change between the four batches due to the difficulty of re-arranging the different floor types in respect to construction.

The manure area consisted of a slatted floor (15% perforation), with a gap width of 18 mm, a gap length of 285 mm and a slat width of 830 mm in all six pens. All groups were fed *ad libitum* on one two-space wet mix feeder per pen with a commercial feed (UFA 330-4: 13.5 MJ DE, 9.7 g/kg lysine, 3.3 g/kg methionine, 50 g/kg crude fibre, 150 g/kg CP). Water was freely available from one nipple drinker in each pen. For enrichment, every pen was equipped with a compressed straw block in a dispenser and a free-hanging hay ball. The enrichment material was available *ad libitum*. The pigs directed only little attention to the rubber mats. Two mats were slightly damaged on the surface at a few places. The pen was cleaned daily if necessary. The pigs did not leave the pens during the 12-week experimental phase except for the two inspections of the claws. A total of 10 pigs died or were removed from the stable during the experimental period, of which four animals were from a pen with rubber mats and six from a pen with concrete elements in the lying area. In all pens, at least one animal had to be excluded. The maximum number of excluded animals was three in the pen with 5% perforated concrete. In five cases, the animal died due to a peracute process (necropsy of one body by researcher: intestinal torsion), one animal was euthanized because of severe lameness (necropsy by Institute of Veterinary Pathology, Vetsuisse Faculty Zurich: abscess in the pelvic region) and four animals were removed and transferred into a separate pen because of lameness or, in one case, inflammation of the tail.

Claw and limb lesions. Each individual was assessed clinically for claw lesions as well as lesions of the limbs at the beginning (average weight: 24.9 ± 3.8 kg), in the middle (average weight: 59.3 ± 8.2 kg) and at the end (average weight: 102.3 ± 12.2 kg) of the 12-week fattening period. This was done by restraining and lifting the animals in a self-designed metal chute. The findings were recorded separately for each claw and limb. The side (right *v.* left), the position on the animal (front or hind) and the position on the foot (lateral or medial) was noted. The assessment was done using the scheme presented in Table 1. Scores between 0 (no lesion) and 3 (severe lesion) were given for each lesion type.

For bursae, we did not follow the previous definitions. Rather, we used the term 'bursa' for all visible and palpable swellings in regions that have been described as being predisposed to the development of auxiliary bursae (Mouttotou *et al*, 1998). In a cross-sectional study, KilBride (2008) found no correlation between the histopathological degree of severity and the previously given scores in a clinical examination of what they assumed to be auxiliary bursae. As this is in accordance with our own observations, we did not score this lesion type, but only recorded its presence or absence.

Table 1 *Description of the lesion scores for the assessment of claw and limb lesions in fattening pigs*

Claw lesions[1]		
Heel erosion	1	Superficially roughened heel and/or desquamation of horn material
	2	Deep loss and/or desquamation of horn substance
	3	Perforation of the epidermis
Horizontal crack	1	Superficial horizontal crack in the wall horn
	2	Deep horizontal crack in the wall horn
	3	Crack perforates into subepidermal structures
Vertical crack	1	Superficial vertical crack in the wall horn
	2	Deep vertical crack in the wall horn
	3	Crack perforates into subepidermal structures
Wall haemorrhage	1	Reddish to light brown discoloration
	2	Red to brown discoloration
	3	Dark discoloration, exceeds 0.5 cm
Separation between heel and sole	1	Palpable shallow indentation
	2	Beginning undermining of the heel horn or moderate gaping
	3	Deep undermining of the heel horn or deep gaping
Lesion of the coronary band	1	Superficial epidermal lesion
	2	Epidermis broken
	3	Deep lesion with significant inflammation of the surrounding tissue
Heel haemorrhage	1	Spotty, non-confluent haemorrhages
	2	Confluent haemorrhage, does not exceed one third of the heel
	3	Solid haemorrhage, affects more than one third of the heel
Sole haemorrhage	1	Spotty, non-confluent haemorrhages
	2	Confluent haemorrhage, does not exceed one third of the sole
	3	Solid haemorrhage, affects more than one third of the sole
Limb lesions[2]		
Hyperkeratosis	1	Loss of elasticity, rough, flaky surface
	2	Stratum corneum thickened and discoloured
	3	Hard areas, fissures
Wound	1	Superficial epidermal lesion
	2	Epidermis broken
	3	Deep lesion with significant inflammation of the surrounding tissue
Bursa	1	Visible and palpable lateroplantar, plantar or medial swelling of the hock, laterally on the forearm or in the carpal region

[1]Adapted from Lippuner (2012).
[2]Adapted from Savary *et al.* (2009).

Claw measures. To keep the number of measurements small, only claw width and claw angle were measured on both lateral and medial claws of the right fore and hind limb only. Claw width was measured using a caliper rule on the widest part of the heel. For the measurement of the claw angle a goniometer was used. Measurements were carried out without inflicting pressure on the tissue. All assessments of claw health and all measurements of claw dimensions were done by the same trained researcher.

Statistical analyses

All statistical analyses were carried out in R (version 3.4.0, R Development Core Team, 2017). It is likely that the occurrence of each lesion type on the different claws (front, hind, lateral, medial) as well as the different lesion types are correlated. Therefore, we condensed the single claw assessments. In a first approach, we subjected the lesion scores of the four claws and the five types of lesions 'heel erosion', 'wall haemorrhage', 'crack horizontal', 'crack vertical', 'sole haemorrhage' (4 claws $\times$ 5 types totalling in 20 variables) to a principle component analysis. We used a standard principal component approach (function princomp in R) but based this approach on a correlation matrix of polychoric correlations (function hector in package polycor; Fox, 2016) between the lesion scores because they are represented as categorical variables. In this evaluation, the first principle component only explained very little of the variance and the cumulative variance explained increased only incrementally from one principle component to the next. Accordingly, the pattern of factor loadings was inconsistent and virtually impossible to interpret.

In a second approach, we first summarised the four lesion scores of the different claws for a given pig at a given time point. We did so by choosing the most severe score that was observed on any of the four legs. This maximum score was then subjected to a principle component analysis based on polychoric correlations including the five types of lesions 'heel erosion', 'wall haemorrhage', 'crack horizontal', 'crack vertical', 'sole haemorrhage'. All maximum scores loaded on the first principle component (with values between 0.36 and 0.52) explaining 48% of the overall variance. All further components were contrasts between the lesion types and therefore not easily interpreted. Due to the estimation based on the polychoric correlations, it was not possible to estimate directly the values of the first principle component for each of our observations. Because the loadings were quite similar, we decided to use the sum of the scores of these five lesion types as our first outcome variable for further statistical evaluation (total claw lesion score).

We proceeded in an analogous way for the leg lesions and the continuous measurements on the legs. We proceeded in an analogous way for the leg lesions and the continuous measurements on the legs (claw width und claw angle). We found that 'hyperkeratosis' and 'bursa' loaded on a first principle component explaining 53% of the variance with values of 0.70 each, whereas the much rarer wounds loaded on the second component (loading 0.98, cumulative variance explained: 0.86). Therefore, we used the summed score of hyperkeratosis and bursa as our second outcome measure (total leg lesion score). We also found that claw width and claw angle were highly correlated in that they both loaded with a value of 0.71 on a first principle component explaining 84% of the variance. We used 'average claw angle' across the four claws as our third outcome measurement.

The total claw lesion score, total leg lesion score and average claw angle were each used as an outcome variable. Model assumptions were examined using graphical analysis of residuals in respect to the normality of errors and random effects as well as the homoscedasticity of the errors. To satisfy assumptions, the total scores plus 0.5 were log-transformed whereas the claw angle was left untransformed. The experimental design was reflected in the random effect of the model: we used animal ID nested in group nested in batch as our hierarchically nested random effect. In respect to the fixed effects, we selected a final statistical model for each outcome based on the model probabilities (model weights) derived from the Bayesian information criterion within a set of models. The model probability reflects the probability of each model in the set being optimal in respect to high predictive power but few predictor variables given the data. The set comprised models that differed in how main effects and their possible interactions were combined. Starting with a maximum model, we performed an all subset analysis using the function 'dredge' in the package 'MuMin' (Barton, 2012) because we had little prior knowledge of the expected effects.

The maximum model included the fixed effects material (factor with two levels: rubber mat or concrete elements), grade of perforation (factor with three levels: 0%, 5%, 10%), assessment time (factor with three levels: B, M, E), and all their potential interactions. These were included because they all make biologically sense and we had little prior knowledge about which interactions to expect. In addition, sex (factor with two levels: females, castrated males) was added as a main effect to account for this nuisance variable.

Results

The total claw lesion score increased from the beginning to the end of the fattening period with a smaller increase in the second half of the period (model with assessment time only: $w_i = 0.48$, $ER_0 > 956$; Figure 1). The values were slightly lower for animals kept on rubber mats than on concrete (second most likely model with main effects of material and assessment time: $w_i = 0.40$, $ER_0 > 806$; all other models had $w_i < 0.06$).

The total leg lesion score showed a more monotonous increase throughout the fattening period and also had lower values in animals kept on rubber mats than on concrete (model with main effects of material and assessment time: $w_i = 0.59$, $ER_0 > 1174$; Figure 1). The effect of the material was more weakly supported because the second best model

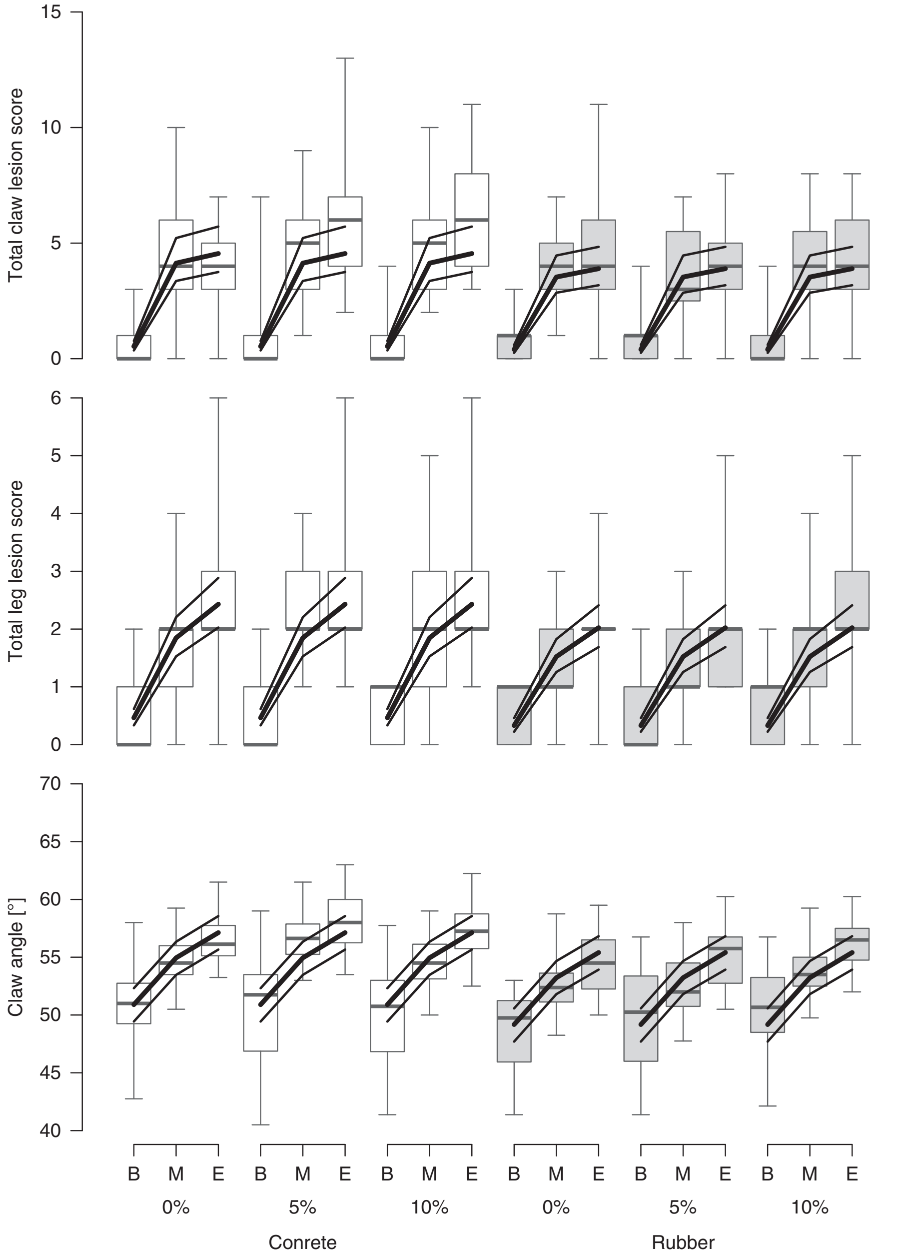

Figure 1 Distribution of total claw lesion score, total leg lesion score and claw angle (from top to bottom) in fattening pigs kept on concrete and rubber floors at three assessments (B = begin of fattening period; M = middle of fattening period; E = end of fattening period) in different perforation percentages (0%, 5%, 10%). For the prevalence data: white = in pens with concrete lying area; grey = in pens with rubber mats. Lines represent model estimates and 95% confidence intervals.

included assessment time only ($w_i = 0.29$, $ER_0 > 574$; all other models had $w_i < 0.08$).

Claw angle also increased almost continuously throughout the fattening period and were lower in animals kept on rubber mats than on concrete (model with main effects of material and assessment time: $w_i = 0.61$, $ER_0 > 1222$). There was a weak indication that castrated males had larger claw angles than females (second best model additional including the sex of the animals $w_i = 0.21$, $ER_0 > 414$; all other models had $w_i < 0.10$).

We found no indication that the grade of perforation had an effect on any of these outcome variables (the fixed effect was never chosen in a model with high w_i).

Discussion

Effect of time

Claw lesions. The total claw lesion score rose from the beginning to the end of the fattening period on all floor variants. The total claw lesion score in this study was composed of the lesion types heel erosion, wall haemorrhage, horizontal crack, vertical crack and sole haemorrhage.

Generally, heel erosions were highly prevalent in all claw locations. This is in accordance with findings of Lippuner (2012) and Gillman *et al*. (2009) who reported a prevalence of heel lesions of 28.4% and 10.8%, respectively. The heel region is characterised by horn material with fewer horn tubuli (Geyer, 1979) and a difference in keratin composition (Webb, 1984) compared with other parts of the horny box. It is therefore relatively soft. Besides abrasive wear of the volar surface (McKee and Dumelow, 1995), it may be assumed that prior impairment of the tissue provokes heel lesions (Newton *et al.*, 1980). Gillman *et al.* (2009) found a relationship to bleeding of the heel. Trauma to the heel region may have occurred in all different floor conditions in the experiment presented here, possibly either because the rubber mats provided were harder than the soft heel horn or because all animals had access to a perforated concrete floor in the defecation area. Newton *et al.* (1980) and Penny *et al.* (1963) assumed that the weakened and roughened heel horn is susceptible to secondary bacterial infection which possibly leads to continuous degradation of the regrowing horn tissue. Mouttotou *et al.* (1999a) related lesions on the volar face of the claw to enhanced pressure on the weight-bearing surface. Accordingly, it could be hypothesised that the pressure strains may lead to or worsen heel erosions as they grow with the animals' weight over time.

Wall haemorrhages have been described as occurring when a claw sinks into a gap hitting its wall against the slat rim (Geyer, 1979). They are visible in the horn substance while they grow down (Geyer, 1979) until they are worn off with the horn. Therefore, an accumulation of older and fresher lesions over the fattening period may have occurred.

Horizontal cracks are considered to be outgrowing remains of earlier wounds of the coronary band (Newton *et al.*, 1980), which also occur when the claw sinks into a gap. Therefore, the explanations we gave for the prevalence of wall haemorrhages may also apply for horizontal cracks. Vertical cracks typically occurred at the junction between the abaxial horn wall and the softer heel horn in our study. This region of the claw has been described as being vulnerable and therefore predisposed to the formation of cracks (Geyer, 1979). As the strains rise with the rising BW of the animals, this lesion type may have become more prevalent towards the end of the fattening period. Vertical cracks can suddenly progress and become painful when they reach into deeper layers or become infected (Geyer, 1979).

Limb lesions. The total leg lesion score also increased in prevalence over the fattening period. Limb lesion types examined in this study were auxiliary bursae, hyperkeratosis and wounds. Auxiliary bursae can be seen as pathologic remodelling processes and typically form over bony prominences with little soft tissue cover. Persistent or recurring friction and pressure lead to the formation of a fluid-filled cavity in the subcutaneous connective tissue (Adams, 1974; Jensen *et al.*, 2012, cited in Mouttotou *et al.*, 1999b). Oberländer (2016) found signs of inflammation in more than 85% of bursal tissue samples in histopathologic examination. This emphasises the meaning of this lesion type for the well-being of pigs, as inflammation is likely to be painful in its acute state. Areas predisposed to the formation of bursae on the hind legs are mainly located on the lateroplantar, plantar and medial aspect of the hock and the point of the hock (Mouttotou *et al.*, 1999b; Gillman *et al.*, 2008). A high prevalence of bursae in finishing pigs was reported in previous studies. Oberländer (2016) observed a prevalence of 91.8% in pigs kept on fully or partly slatted concrete floors and examined at slaughter. Quinn (2014) found a prevalence of 29.6% in weaner and finishing pigs kept on floors made of different materials, without bedding and with different perforation percentages. The increase of bursae over time is in accordance with other studies investigating bursae in finishing pigs. Ekkel *et al.* (2003) found that the increase in the prevalence of bursae was related to weight gain and the greater amount of time older pigs spent lying. KilBride (2008) suggested that the rising prevalence may indicate that some bursae become chronic and therefore accumulate over time. Hyperkeratosis of the skin is provoked by chronic excessive pressure or friction (Freeman, 2002). As pressure strains on the joint areas increase with the animals' weight gain during the fattening period, hyperkeratosis progressed in affected animals over time, similar to observations made by Savary *et al.* (2009). Unlike all other lesion types, hyperkeratosis was already highly prevalent at the first assessment, but only on the fore legs, where they possibly remain from the suckling period. However, hyperkeratosis on the hind legs developed in the experimental phase of our study. The results on limb lesions show that all tested variants of floor in the experimental pens did strain the skin.

Effect of the surface material in the lying area

Claw lesions. The total claw lesion score was lower in pigs kept on rubber mats compared with pigs kept on concrete. The greater softness and therefore flexibility of rubber absorbs pressure forces (De Carvalho *et al.*, 2009), may reduce slipping by providing more traction (Von Wachenfeldt *et al.*, 2010), and may lead to more even weight distribution between the lateral and medial claws.

Several authors describe a decrease in prevalence of claw lesions in pigs kept in bedded pens, which is also likely to be an effect of the greater softness compared with concrete floors without bedding. For example, Rähse (2006) found an overall prevalence of 28.4% for moderate to severe claw lesions (deformities, pressure sores and contusions, indentations, heel lesions, cracks) in finishing pigs kept in pens with deep-straw bedding compared with 58.8% in pens without bedding and 65.9% in pens with sparse straw bedding. Scott *et al.* (2006) also found reduced severity scores for some (sole and heel erosions), but not all (toe erosions, white line lesions) claw lesions in post-slaughter examinations of pigs kept in pens with straw bedding compared with pigs kept on fully slatted concrete floors. They explain the even higher incidence of toe erosions in straw-bedded pens, which is also in line with findings of Mouttotou *et al.* (1999a), with dampness and poor hygiene in the straw bedding which weakens the claw horn substance. This disadvantage of straw bedding probably does not apply for rubber mats. Still, first studies on the effect on claw lesions in breeding sows are contradictory, as Calderon Diaz *et al.* (2013) found a greater risk for toe erosion, heel-sole crack, crack in the wall and white line lesion in breeding sows kept in pens equipped with rubber slat mats during two parities. Baumann *et al.* (2012) reported a stagnation in incidence of breeding sows with abrasion of the wall and haemorrhage from the time they were stalled in pens with rubber mats in the lying area, whereas sows in pens with concrete in the lying area showed a rising incidence in these characteristics. These results, of course, relate to heavier adult animals, which also probably already acquired predispositions (Newton *et al.*, 1980) and deformities before entering the studies. Therefore they might not be directly comparable with the present study, in which the animals showed almost no claw lesions at the initial examination and for which we assume that almost all lesions newly developed under the experimental floor conditions.

Limb lesions. Pigs kept in pens with rubber mats showed a lower total leg lesion score. Gillman *et al.* (2008) suggested that the formation of auxiliary bursae is a response to lying rather than walking on hard surfaces, as the risk of this lesion type decreased when bedding material was provided, as also shown by Mouttotou *et al.* (1999b) and Oberländer (2016). Studies by KilBride (2008) showed that roughness of the floor can add to the higher risk of bursae in pigs lying on hard floor. The rubber mats in the present study seemed to be flexible and smooth enough to reduce this risk. KilBride (2008) also identified slipperiness as a risk factor for bursae. The greater traction of rubber compared with concrete (Von Wachenfeldt *et al.*, 2010) may lead to a decrease in slipping events. This may also explain a reduced prevalence of wounds, which, among other reasons, may occur as injuries when the animals slip. As the occurrence of hyperkeratosis, as explained before, seems to be related to pressure strains, a reduction of this lesion type is also thinkable.

Claw angles. Claw angles of all claws were smaller in pigs kept in pens with rubber mats. As rubber is softer (Von Wachenfeldt *et al.*, 2010) than concrete, we assume that there was less mechanical wear-off in the claws of pigs kept on the mats. The resulting greater total length-growth of the claw horn resulted in smaller claw angles.

Effect of floor perforation

There was no effect of floor perforation on neither the total claw lesion score nor the total leg lesion score in this study. Some other studies which investigated the effect of floor perforation show an increased risk for different limb and claw lesions (Geyer, 1979; Scott *et al.*, 2006; KilBride, 2008), but several authors also report a lack of an effect (Mouttotou *et al.*, 1999b; Rähse, 2006). Newton *et al.* (1980) hypothesize that perforation of the floor has no overriding effect on claw and leg health and suggests that traction, roughness and abrasiveness are the main influence factors on the development of lesions. In the present study, it also has to be taken into account, that all animals had access to a slatted concrete manure area.

Conclusions

The present data show that rubber mats in the lying area bring about improvements in some aspects of claw and leg health in fattening pigs, whereas there was no effect of floor perforation. The reduced incidence of lesions may contribute to the animals' welfare, as some of the investigated lesion types are likely to be painful.

Acknowledgements

The authors would like to thank the staff of the experimental stables, Andreas Hagenbüchli and Barbara Ammann, for their support and excellent care of the animals. Special thanks goes to Esther Bürgi for her generous professional advice. We would also like to thank Agroscope, Tänikon, for the use of their research facilities and the Swiss Federal Food Safety and Veterinary Office for funding this study (Project No. 2.13.05).

References

Adams OR 1974. Lameness in horses, 3rd edition. Lea and Febiger, Philadelphia, PA, USA.

Barton K 2012. MuMIn: Multi-model inference. R package version 1.7.11. Retrieved on 12 December 2017 from https://cran.r-project.org/web/packages/MuMIn.

Baumann S, Pflanz W, Gallmann E and Schrader L 2012. Assessing sow foot health in various types of housing. Landtechnik 67, 413–416.

Bos E-J, Van Riet MM, Maes D, Millet S, Ampe B, Janssens GPJ and Tuyttens FAM 2016. Effect of rubber flooring on group-housed sows' gait and claw and skin lesions. Journal of Animal Science 94, 2086–2096.

Calderon Diaz JA, Fahey AG, KilBride AL, Green LE and Boyle LA 2013. Longitudinal study of the effect of rubber slat mats on locomotory ability, body, limb and claw lesions, and dirtiness of group housed sows. Journal of Animal Science 91, 3940–3954.

De Carvalho VC, de Alencar Nääs I, Neto MM and Lucas de Souza SR 2009. Measurement of pig claw pressure distribution. Biosystems Engineering 103, 357–363.

Ekkel ED, Spoolder HAM, Hulsegge I and Hopster H 2003. Lying characteristics as determinants for space requirements in pigs. Applied Animal Behaviour Science 80, 19–30.

Fox J 2016. polycor: Polychoric and Polyserial Correlations. R package version 0.7-9. Retrieved on 12 December 2017 from https://CRAN.R-project.org/package=polycor.

Freeman DB 2002. Corns and calluses resulting from mechanical hyperkeratosis. American Family Physician 65, 2277–2282.

Geyer H 1979. Morphologie und Wachstum der Schweineklaue, Grundlagen für Stallbodengestaltung und Klauenpathologie. Habilitation dissertation, University of Zurich, Zurich, Switzerland.

Gillman CE, KilBride AL, Ossent P and Green LE 2008. A cross-sectional study of the prevalence and risk factors for bursitis in weaner, grower and finisher pigs from 93 commercial farms in England. Preventive Veterinary Medicine 83, 308–322.

Gillman CE, KilBride AL, Ossent P and Green LE 2009. A cross-sectional study of the prevalence of foot lesions in post-weaning pigs and risks associated with floor type on commercial farms in England. Preventive Veterinary Medicine 91, 146–152.

Jensen T, Nielsen CK, Vinther J and D'Eath RB 2012. The effect of space allowance for finishing pigs on productivity and pen hygiene. Livestock Science 149, 33–40.

Jorgensen B 2003. Influence of floor type and stocking density on leg weakness, osteochondrosis and claw disorders in slaughter pigs. Animal Science 77, 439–449.

KilBride AL 2008. An epidemiological study of foot, limb and body lesions and lameness in pigs. PhD thesis, University of Warwick, Coventry, UK.

Larson G, Dobney K, Albarella U, Fang M, Matisoo-Smith E, Robins J, Lowden S, Finlayson H, Brand T, Willerslev E, Rowley-Conwy P, Andersson L and Cooper A 2005. Worldwide phylogeography of wild boar reveals multiple centers of pig domestication. Science 307, 1618–1620.

Lippuner A 2012. Klauengesundheit von Schlachtschweinen, KB-Ebern und Muttersauen in der Schweiz und genetische Analyse von Klauenparametern. Doctoral dissertation, University of Zurich, Zurich, Switzerland.

McKee CI and Dumelow J 1995. A review of the factors involved in developing effective non-slip floors for pigs. Journal of Agricultural Engineering Research 60, 35–42.

Mouttotou N, Hatchell FM and Green LE 1998. Adventitious bursitis of the hock in finishing pigs: prevalence, distribution and association with floor type and foot lesions. The Veterinary Record 142, 109–114.

Mouttotou N, Hatchell FM and Green LE 1999a. Foot lesions in finishing pigs and their associations with the type of floor. The Veterinary Record 144, 629–632.

Mouttotou N, Hatchell FM and Green LE 1999b. Prevalence and risk factors associated with adventitious bursitis in live growing and finishing pigs in south-west England. Preventive Veterinary Medicine 39, 39–52.

Newton GL, Booram CV, Hale OM and Mullinix BG 1980. Effect of four types of floor slats on certain feet characteristics and performance of swine. Journal of Animal Science 50, 7–20.

Oberländer S 2016. Untersuchungen zum Vorkommen von akzessorischen Bursen bei Mastschweinen. Doctoral dissertation, Ludwig-Maximilians-University Munich, Munich, Germany.

Penny R, Osborne A and Wright A 1963. The causes and incidence of lameness in store and adult pigs. Veterinary Record 75, 1225–1235.

Quinn AJ 2014. Limb health in pigs: the prevalence and risk factors for lameness, limb lesions and claw lesions in pigs, and the influence of gilt nutrition on indicators of limb health. PhD thesis, University of Warwick, Coventry, UK.

Rähse E 2006. Untersuchungen zu Klauenmaßen und Klauenveränderungen bei Mastschweinen unter Beachtung der Haltungsbedingungen. Doctoral dissertation, Justus-Liebig-University, Giessen, Germany.

R Core Team 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Savary P, Gygax L, Wechsler B and Hauser R 2009. Effect of a synthetic plate in the lying area on lying behaviour, degree of fouling and skin lesions at the leg joints of finishing pigs. Applied Animal Behaviour Science 118, 20–27.

Scott K, Chennells DJ, Campbell FM, Hunt B, Armstrong D, Taylor L, Gill BP and Edwards SA 2006. The welfare of finishing pigs in two contrasting housing systems: fully-slatted versus straw-bedded accommodation. Livestock Science 103, 104–115.

Von Wachenfeldt H, Nilsson C and Pinzke S 2010. Gait and force analysis of provoked pig gait on clean and fouled rubber mat surfaces. Biosystems Engineering 106, 86–96.

Webb NG 1984. Compressive stresses on, and the strength of, the inner and outer digits of pigs' feet and the implications for injury and floor design. Journal of Agricultural Engineering Research 30, 71–80.